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REGION 5
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RE: Recommended Management Practices based on the Removal Action at the Warren Recycling / Warren Hills Landfill Site

Dear Mr. Harris and Ms. Snyder,

As you know, one of the objectives of U.S. EPA's recent removal action at the Warren Recycling Site ("Site"), Warren, Trumbull County, Ohio, was to develop "Recommended Management Practices" (RMPs) based on our experiences while conducting this challenging cleanup. This Site was an example of how dangerous construction and demolition (C&D) debris landfills can become if not properly managed to control the potential generation of highly concentrated hydrogen sulfide gas. Over the past year, we have committed to the local public to develop the RMPs in the hope that other C&D debris landfills in the State of Ohio recognize these potential dangers and avoid becoming a community health threat.

The enclosed document was developed by U.S. EPA Region 5's Waste Management Branch, in consultation with our multi-agency Site team. The recommendations in this enclosure have been thoroughly reviewed and edited by those who have developed extensive experience with hydrogen sulfide generation and response issues at C&D debris landfills. I hope you will find this useful as you continue to assist and regulate the C&D debris community.

If you have questions, feel free to call me at 440-250-1743, or Ramon Mendoza, in our Waste Management Branch, at 312-886-4314.

Sincerely,

Mark Durno,
On-Scene Coordinator

ENCLOSURE

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ENCLOSURE

Management Practices to Prevent and Control Hydrogen Sulfide Gas Emissions at C&D Debris Landfills Which Dispose of Pulverized Gypsum Debris in Ohio

1.0 Introduction

Construction and demolition (C&D) debris landfills that dispose of large amounts of gypsum wallboard that has been pulverized into a powder form have the potential to emit hydrogen sulfide (H_2S) gas at potentially harmful levels under certain conditions. This document provides information on when this may occur and the management practices that may be instituted to prevent such emissions. In most cases, the disposal of gypsum wallboard in C&D debris landfills would not present such a problem. Thus, this document is focused on those C&D debris landfills where the release of H_2S may be an issue. This document does not apply to municipal solid waste landfills that use C&D fines as alternative daily cover.

The information presented in this document, unless otherwise noted, is primarily based on our knowledge and experience gained from our time-critical removal action at the Warren Recycling Inc. (WRI) C&D Landfill Site, and discussions from a collaborative group which included officials from the United States Environmental Protection Agency (USEPA) Region 5, USEPA Office of Research and Development (ORD), Agency for Toxics Substances and Disease Registry, & Ohio Environmental Protection Agency (OEPA). For further information and questions on this matter, you should contact:

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1.1 Background

A major source of H_2S gas emissions at C&D debris landfills in Ohio has been attributed to the disposal of large amounts of pulverized gypsum wallboard in powdered form. H_2S gas emissions may occur from the aforementioned debris if conditions and/or operational practices result in the pulverized gypsum drywall coming in contact with moisture under anaerobic conditions. Because of H_2S's objectionable rotten-egg like odor, owners of disposal facilities that emit H_2S gas may find themselves facing numerous complaints from the surrounding communities. Operators of these landfills often expend resources to modify their operational practices, and conduct other actions to reduce odors caused by the H_2S gas.

In general, this document is based on current industry and regulator experience in Ohio, case studies (including Warren Recycling Inc.), academic research (such as from the University of Florida) conducted on the subject matter and experiences from other states.

The management practices described in this document are provided as recommendations.

1.2 Conditions at WRI C&D Debris Landfill and Summary of USEPA Time-Critical Removal Action:

The WRI Site was one of a number of C&D debris landfills in Ohio. Improper operating practices and environmental conditions at WRI (poor storm water/surface water control, no consistent cover, large amounts of pulverized gypsum, anaerobic environment, organic sources, and ideal ph and temperatures) led to the release of H_2S gas at levels that posed an imminent threat to nearby residents and schoolchildren.

The 200-acre WRI site, located in Warren, Ohio, was operated as a C&D debris landfill from 1994 to 2004. The site is located in a mixed commercial and residential area. Residential homes are within 100 feet of the facility. A high school and elementary school were located within 1 mile of the facility.

OEPA estimated that sometime in Dec. 2002 or early 2003, WRI started accepting and disposing of large amounts of pulverized C&D debris (arrived by rail). This pulverized C&D debris has been crushed to the extent that the majority of the gypsum drywall was in a powder form. OEPA indicated that the C&D debris at WRI had a density of 2.5 to 2.8 cubic yards/ton. From January 2003 to June 14, 2004, OEPA estimates that the facility accepted and disposed of 1,762,412 cubic yards (704,965 to 629,432 tons) of pulverized C&D debris. According to inspections by OEPA during this period, C&D debris was not covered on a regular basis. In addition, stormwater was not diverted away from the working face of C&D debris resulting in large amounts of leachate. This leachate was allowed to stand in permanent leachate ponds. Consequently, OEPA cited the facility several times for violations of its C&D debris regulations.

According to OEPA, the odor problem became more serious during the aforementioned period. Residents complained of a rotten egg smell and health symptoms, particularly those to the north and west of the landfill. Based on the results of extensive air sampling, the ATSDR concluded in November 2003 that exposure to H_2S gas presented an urgent public health threat to the neighboring community. Federal, state and local agencies worked cooperatively to bring WRI into compliance with state and local laws, eventually requiring the facility to submit a plan that would resolve the environmental problems and permanently close the landfill. Because the company had not complied with this order, USEPA began an interim ("time-critical") cleanup in 2005 to reduce the immediate health threat posed by the H_2S gas. [1]

USEPA and its contractors collected all loose construction and demolition debris on the property and placed it in the open face of the landfill. The open face at WRI had been left uncovered and exposed to the elements when the company operating the landfill went out of business. USEPA then covered the open face with a temporary clay cap to keep rainwater out of the landfill.

Before the USEPA cleanup, rainfall and snowmelt had been allowed to collect in ponds, pits and other low areas surrounding the landfill. In fact, standing water bordered nearly half the southwest section, and when water reached the gypsum-containing debris, hydrogen sulfide gas was produced. USEPA solved this problem by draining and filling with clean clay all areas of standing water surrounding the southwest portion. To ensure proper drainage in the future, a large ditch was constructed to carry rain and melted snow away from the landfill. In addition, the surrounding land was graded (sloped) so water would flow into the drainage ditch and away from the landfill.

USEPA constructed a temporary cap of compacted clay to cover the southwest portion of the landfill. The cap, more than a foot thick, will keep rain and snow from soaking into the landfill and mixing with the debris, thus substantially reducing the formation of hydrogen sulfide gas. To reduce future soil erosion, the cap will be seeded. This cap is a temporary measure designed to address the immediate health risk associated with the gas. When the landfill is permanently closed, this cap may need to be made thicker to conform to OEPA requirements.

The stormwater management system is designed to carry away water collecting on or near the landfill, and the cap prevents new water from seeping into the landfill. USEPA also had to remove a large portion the contaminated water (or leachate) trapped inside the landfill. USEPA designed and installed a system of pipes and pumps to draw the leachate from the landfill and surrounding ponds. The leachate is treated on-site, and is then discharged into the local sanitary sewer. By May 2006, over 13 million gallons of leachate have been collected, treated and discharged. Leachate levels inside risers of the landfill's collection pad have decreased from 13 feet deep to 6 feet in the six months the system has been operating, and levels are expected to drop further as it continues to operate.

[1] After analyzing measurements across the entire surface of the landfill, USEPA determined that the only portion of the landfill needing immediate cleanup was the tallest of three sections located in the area known locally as the southwest section. The other two sections of the landfill also produce H_2S gas, but, the levels of gas do not pose an immediate public health risk.

The aforementioned response action provided knowledge and experience that can be used to prevent and control H_2S gas at other similar sites. These sites are C&D debris landfills that dispose of large amounts of gypsum wallboard that has been pulverized into a powder form where the gypsum is exposed to moisture and anaerobic conditions.

In July 2006, a final site survey of hydrogen sulfide concentration was conducted. The survey was conducted in the same manner as the pre-removal survey. Utilizing a low-level calibrated hydrogen sulfide monitor, data was collected at the surface of the landfill on a grid of 50-foot intervals. The results were dramatic. With similar meteorological conditions, the hydrogen sulfide maximum concentration was reduced from 165 parts per million (ppm) in May 2005 to .043 ppm in July 2006.

For more detailed information about USEPA's time critical removal actions at WRI please go to: http://www.epaosc.org/WarrenRecycling , or contact Mark Durno, the USEPA federal on-scene coordinator for the site.

2.0 Hydrogen Sulfide Gas (Note: Unless otherwise noted all information regarding H_2S comes from ATSDR, References 1 & 1a)

This section provides information which describes H_2S gas characteristics and levels that have been established at the federal level to protect on-site workers (including personnel doing monitoring activities) and off-site residents. The information also may be used as a reference to educate the community and assist in the development of site-specific monitoring and action plans.

H_2S Gas Characteristics : H_2S is a flammable (explosive limit between 4% and 45% in air, Ref. 2), colorless gas with a characteristic strong odor of rotten eggs. It is also known as hydrosulfuric acid, sewer gas, sulfuretted hydrogen, hydrosulfuric acid, hepatic gas, sour gas, and stink damp. H_2S is a naturally occurring gas that is found in crude petroleum, natural gas, volcanic gases, and hot springs. There are also anthropogenic (man made) sources of H_2S gas, such as from food processing, coke ovens, paper manufacturing mills, tanneries, solid waste disposal facilities, petroleum refineries and waste water treatment plants.

Humans can smell H_2S gas at low levels (0.0005 to 0.3 parts per million [ppm]). However, at higher concentrations, at or above 100 ppm, individuals may not detect H_2S gas due to olfactory fatigue. Olfactory fatigue is a condition that inhibits the ability to smell particular substances, usually due to overexposure. Olfactory fatigue can occur from acute (immediate) exposure to high concentrations and from chronic (continuous) exposures to low concentrations. For this reason, odor is not a reliable indicator of H_2S's presence and may not provide adequate warning of hazardous concentrations. H_2S gas is slightly heavier than air and may accumulate in enclosed, poorly ventilated, and low-lying areas. When released, H_2S gas may be converted into sulfur dioxide, which is one of the six priority pollutants that are subject to the national ambient air quality standards (Ref. 20). H_2S gas also is readily soluble (3,700 milligrams/liter) in water, thus when liquids contaminated with H_2S gas are exposed to the air, dissolved H_2S gas may be emitted to the atmosphere.

Residential Scenario Screening Levels for H_2S Gas*:* Off-site residents who live near disposal facilities which emit H_2S gas may experience longer exposure periods than on-site workers. Because of the potential for a longer exposure period, the unsafe H_2S gas level for off-site residents may be lower than what it would be for on-site workers. Currently, there are no enforceable federal standards for off-site H_2S gas emissions from landfills. As mentioned earlier, various USEPA Regions and some states have developed guidance and criteria for H_2S gas, none of which specifically address emissions from C&D debris landfills. Specifically:

- Two USEPA regions have published risk based screening levels which may be applied to residential exposure scenarios. Preliminary remediation goals in ambient air of 0.00072 ppm and 0.0015 ppm of H_2S gas have been established by USEPA Region 9 (Ref. 3) and 3 (Ref. 4), respectively. The US EPA in the aforementioned regions considers H_2S gas concentration at these levels and below to be safe, where exposure over 30 years, 24 hours a day will not result in a public health threat. These are not considered levels at which a response action is warranted.

- USEPA has published Acute Inhalation Exposure Guidelines (Ref. 5) defined as "the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure." For H_2S gas, the values were set at 0.51ppm (1hour exposure time), 0.36ppm (4 hour exposure time), & 0.33 ppm (8 hour exposure time).

Other organizations, including other federal agencies, also have developed guidance or criteria for exposure to H_2S gas. Specifically:

- The Agency for Toxic Substances and Disease Registry (ATSDR) has noted that exposure to low concentrations of H_2S gas may cause irritation to the eyes, nose, or throat. It may also cause difficulty in breathing for some asthmatics. Brief exposures to high concentrations of H_2S gas (greater than 500 ppm) can cause a loss of consciousness and possibly death. In most cases, the person appears to regain consciousness without any other effects. However, in many individuals, there may be permanent or long-term effects such as headaches, poor attention span, poor memory, and poor motor function. No health effects have been found in humans exposed to typical environmental concentrations of H_2S (0.00011-0.00033 ppm, ATSDR).

  ATSDR has derived minimum risk levels (MRLs) for H_2S gas based on inhalation exposure. An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. These substance specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies. For H_2S gas, the MRLs are 0.070 ppm for acute (0-14 day) exposure and 0.030 ppm for intermediate (14-365 day) exposure durations. It is important to note that ATSDR has drafted new MRLs for H_2S gas. (.2ppm acute MRL, .02 intermediate MRL). These MRLs are undergoing public comment and have not been adopted as of the date of this document.

- The American Industrial Hygiene Association (AIHA) has established an ERPG-1 (Emergency Response Planning Guideline) for H_2S gas of .1 ppm as a 60 minute time weighted average concentration. This value is a recommended action level that is intended to be protective of all human populations.

On-Site Worker Levels for H_2S Gas: The Occupational Safety and Health Administration (OSHA) has established a permissible exposure limit (PEL) for general industry of 20 ppm with the following exception: if no other measurable exposure occurs during the 8-hour work shift, exposures may exceed 20 ppm, but not more than 50 ppm for a single time period up to 10 minutes. The National Institute for Occupational Safety and Health (NIOSH) adopted a recommended exposure limit (REL) of 10 ppm for H_2S gas. Furthermore, NIOSH has set a limit of 100 ppm of H_2S gas as immediately dangerous to life or health (IDLH). (Ref. 7).

The following table summarizes the aforementioned H_2S gas standards, guidelines, and screening levels:

Hydrogen Sulfide Gas Standards, Guidelines, & Screening Levels	**Concentration**
Hydrogen Sulfide Olfactory Lower Range	0.0005- 0.3 ppm
Hydrogen Sulfide Olfactory Fatigue	100 ppm (at 2-15 minute exposure)
USEPA Region 9 Preliminary Remediation Goal ; Chronic exposure (residential) scenario, 30 years 24 hours a day, taking into account child exposure	0.0007 ppm
USEPA Region 3 Risk Based Concentration; Chronic exposure (Residential) Scenario, 30 years, 24 hours a day	0.0015 ppm **
USEPA Acute Inhalation Exposure Guideline	0.51 ppm for 1 hour exposure 0.36 ppm for 4 hour exposure 0.33 ppm for 8 hour exposure
American Industrial Hygiene Association (AIHA) ERPG-1 (Emergency Response Planning Guideline)	.1 ppm as a 60 minute time weighted average concentration. *
ATSDR Acute Minimum Risk Level (1-14 day exposure); Intermediate Minimum Exposure Level (15-356 exposure) ***	.070 ppm (acute) * .030 (intermediate) **
OSHA Permissible Exposure Limit , General Industry	20 ppm (50 ppm peak for 10 minutes)
NIOSH Recommended Exposure Limit (40 hours)	10 ppm
NIOSH Immediately Dangerous to Life or Health	100 ppm

* USEPA site-specific action level used at WRI time-critical removal action

** USEPA site-specific cleanup level used at WRI time-critical removal action

*** ATSDR has published new draft MRLs (undergoing public comment), .2ppm acute MRL & .02 intermediate MRL.

3.0 How Hydrogen Sulfide Gas is Generated at C&D Landfills.

Gypsum drywall (also known as gypsum wallboard or drywall) is one of the major components of the C&D debris waste stream as presented in Table 1-1 (Ref. 8, 9) . Gypsum is composed of calcium sulfate dehydrate ($CaSO_4 \cdot 2H_2O$) and is the major component of drywall (Ref. 10).

Composition of the C&D Waste Stream in the United States from Construction Activities (Ref. 8,9)

Component	Percent Composition by Mass
Concrete and mixed rubble	40-50%
Wood	20-30%
Drywall	5-15%
Asphalt roofing	1-10%
Metals	1-5%
Bricks	1-5%
Plastics	1-5%

Pulverized gypsum drywall has been identified as the major contributor for H_2S gas production and emissions in C&D landfills (Ref. 10, 11 &12). Drywall consists of 90% gypsum and 10% paper (Ref. 10). When wetted, the sulfate in the drywall dissolves into solution. H_2S gas is generated as a result of a series of reactions that biologically reduce the sulfate leached from the gypsum board under anaerobic (absence of air) conditions like those prevalent at many C&D debris landfill sites (Ref.10). Under these anaerobic conditions, sulfate reducing bacteria (SRB) produce H_2S gas from the sulfate (SO_4^{-2}) in gypsum and the organic carbon waste materials as follows (Ref.10,12):

$$SO_4^{-2} + 2CH_2O \Rightarrow 2HCO_3^{-1} + H_2S$$

Based on stoichiometery alone, one hundred tons of sulfates have the potential to produce thirty five tons of H_2S gas (Ref. 12). Research suggests that in C&D debris landfills, SRBs are the primary microorganisms responsible for generating H_2S gas (Ref.10). SRBs use sulfur as an electron acceptor when oxidizing organic matter during the respiration process (Ref. 10). Apart from requiring the bacterial community to be present, in this case SRBs, specific conditions are required for SRBs to generate H_2S gas:

a. A good source of sulfate, in this case, is gypsum drywall: Gypsum drywall enters C&D debris landfills from several different locations, including manufacturing facilities, construction sites, renovation activities, building demolitions, disaster debris, and manufactured housing plants (Ref. 10).

b. Presence of organic matter: Because of its paper backing and some of the starchy binding additives used in the manufacturing process, drywall contains both the sulfate and organic matter to sustain a viable community of SRBs that potentially may generate H_2S gas (Ref. 10,11,13). It is noted that the H_2S gas generation rate in C&D debris landfills is limited by the amount of degradable organic matter in the fill.

c. Wet conditions: The biological conversion of sulfate to H_2S gas must occur in saturated or wet conditions. Water can be present from the waste and from precipitation. The uncontrolled introduction of surface water or storm water run on, run off and ponding can lead to a wet environment within the landfill and may cause H_2S gas generation. (Ref. 10,11,14).

[Note: States (with federally approved solid waste programs) and federal criteria for C&D debris landfills have requirements applicable to C&D debris landfills which require the control of surface water & storm water. Compliance with these requirements will contribute to preventing and controlling H_2S gas emissions.]

d. Anaerobic conditions**:** SRBs are strict anaerobic (no oxygen) microorganisms. This means they cannot survive in the presence of oxygen. Anaerobic conditions can be produced within landfills when waste is compacted. However, the introduction of air into C&D debris landfills should not be allowed under any circumstance because of fire potential. (Ref.10,11,13)

e. Neutral pH range**:** SRBs thrive in environments with neutral pH range (6 to 9). The optimum pH for SRBs is approximately 7 (Ref. 10).

f. Temperature between 20 and 39 C (68 and 102.2 F): This temperature range is important for the survival of SRBs (Ref.10).

If the above conditions are *all* present, the SRBs break down the gypsum and H_2S gas is formed. The rate at which H_2S gas is generated depends on many factors like the availability of organic substrate, as well as the other aforementioned conditions. However, when any one of these conditions is absent, the SRBs will not thrive and will not produce H_2S gas (Ref. 11). Thus, this document and the management control practices discussed in the next section are focused on those C&D debris landfills where all these conditions are present.

4.0 H_2S Prevention and Control Management Practices

Many states and C&D landfills have developed good management practices or requirements to control H_2S gas formations in C&D landfills. However, where a particular C&D debris landfill meets all of the conditions, described above, certain management practices (MPs) can be utilized to prevent and control such emissions. This section describes those management practices (MPs) that a C&D debris landfill may utilize to prevent and control H_2S gas emissions. Depending on the site conditions and the magnitude of the problem, one or more of the suggested MPs may be more effective than others. These MPs focus on controlling H_2S gas emissions by either removing an environmental requirement of SRBs or by changing environmental characteristics of the site. Any one or combination of more than one of the MPs may be implemented at a site depending on site-specific conditions and location. Therefore, we recommend that the MPs presented in this text be evaluated separately by the site owner/operator for technical feasibility and cost effectiveness.

4.1 Gypsum Drywall Diversion/Recycling

Gypsum drywall diversion, recycling and reuse of the material is recommended as the first MP examined, if possible. This practice removes or minimizes the gypsum before disposal. Gypsum drywall is commonly used in various recycling and reuse techniques. Source separation has been shown to be an effective method to collect gypsum drywall in a relatively clean fashion, while keeping cost at a minimum. A dedicated covered waste receptacle for drywall tends to facilitate recycling efforts at most construction jobs. For more information about drywall recycling and reuse, visit (https://www.drywallrecycling.org).

pH Control

SRBs require a pH range of approximately 6 to 9 to effectively reduce sulfur to produce H_2S gas. The idea of pH control is to alter the pH of the gypsum drywall to a range that is not hospitable for SRB growth. This can be accomplished by the application of a buffering agent which changes the pH of the system and maintains it at either an alkaline pH >9 or an acidic pH <6. However, since acidic pH in disposal environments may cause concern regarding the mobility of various other contaminants (e.g., metals), the use of acidic buffering agents (pH <6) is discouraged. Controlling the pH at an alkaline environment (pH >9) may provide a relatively safe and cheap method of H_2S gas emission control (Ref. 13). However, for consideration, certain metals, such as arsenic and selenium are more mobile at alkaline pH. Various methods of controlling alkaline pH are discussed below.

An example of pH control is the addition of lime (CaO), (Ref. 13). The use of lime as a treatment for H_2S gas control may also assist in the problems associated with leachate. An increase in the pH reduces the solubility of metallic salts and thus reduces the amount that may migrate to the leachate. Laboratory and field studies conducted at the University of Florida suggest that lime may also act as a sorbent material for H_2S gas, where it attenuates H_2S gas and prevents it from migrating from the landfill surface (Ref. 16).

4.3 Moisture Control (Ref. 16, 17, 18)

One of the required factors for SRBs to produce H_2S gas is moisture. Thus, moisture diversion can play a major role in controlling gaseous emissions, including H_2S, from debris disposal facilities that accept large amounts of pulverized gypsum drywall. Moisture control at such C&D debris landfills may include the management and diversion of storm water, as well as surface water management, and in some cases leachate management.

Specifically, we recommend that moisture infiltration into these types of wastes be controlled by using a surface water run-off management system similar to that found at various municipal solid waste management facilities. Storm water diversion from a debris disposal facility that accepts large amounts of pulverized gypsum drywall is also an important component in moisture control. Designing a proper storm water management system is important for adequate facility drainage and water control. Storm water can be managed with design and construction methods such as silt fences, rock dams, erosion control mats, diversion channels and berms. Such systems reduce the amount of moisture that gets in contact with the C&D debris and will help reduce ponding and leachate volume.

Daily and long-term cover to prevent storm water from infiltrating into the debris containing pulverized gypsum drywall may also be appropriate. Daily covers and long term covers, as will be discussed later, may also play a major role in attenuating H_2S gas emissions. Long-term maintenance and cover erosion controls may be necessary to prevent washout. By maintaining an effective cover, facilities will reduce management costs by preventing the formation of H_2S gas.

In general, C&D debris landfills must comply with state and federal (40 Code of Federal Regulations Parts 257.3-1, 257.3-3, 257.8, 257.9 as appropriate) requirements to control surface water and prevent these types of facilities from being located in areas such as wetlands and floodplains. Compliance with these requirements should contribute to controlling H_2S gas emissions.

At the WRI cleanup, USEPA eliminated the leachate ponds and constructed an effective surface/storm water control system that prevented ponding and reduced the amount of leachate generated, leading to the reduction of H_2S gas emissions.

4.4 Leachate Management (13,18)

Because of H_2S's high solubility in water, leachate from C&D debris landfills that contain H_2S gas may cause odor problems as it migrates off the site. Thus, C&D debris landfill leachate can become a significant source of H_2S gas, especially when sulfate concentrations are elevated. Depending on state and local regulations, C&D debris landfills that accept large amounts of pulverized gypsum drywall, particularly if it is pulverized into a powder form, may be required to collect and manage leachate generated at the site. In such a scenario, the collected leachate may have to be treated for H_2S gas and managed in accordance with specified requirements.

The removal of H_2S from leachate is mainly accomplished by chemical oxidation processes. These processes commonly utilize an oxidizing agent to oxidize H_2S to form elemental sulfur or sulfate depending on the pH. The oxidizing agent may be stored on site and is usually introduced to the leachate at the site before the leachate is transported to the local wastewater treatment plant for further treatment. Leachate recirculation is not recommended as a leachate management option at C&D debris landfills with significant amounts of pulverized gypsum. The recirculated leachate provides both the moisture and microbial seed, thus promoting further H_2S gas generation.

At the WRI cleanup, USEPA dewatered and filled in the leachate ponds and installed an effective leachate treatment and disposal system to effectively control H_2S gas emissions (Ref. 18).

4.5 Capping/Cover/Alternative Cover Materials (Ref. 16, 17, 18,19)

Temporary and permanent covers are effective in reducing H_2S gas emissions from C&D debris landfills by controlling and reducing the moisture and attenuation of H_2S gas emissions. Section 4.3 discussed the use of cover material to control moisture. This section will address issues regarding the use of various cover materials as passive treatment systems for H_2S gas emissions from C&D debris landfills.

Research conducted at the University of Florida concluded that cover materials can effectively reduce H_2S gas emissions from C&D debris landfills. Apart from its thickness, cover effectiveness largely depends on the physical and chemical characteristics of the cover material. These studies concluded that lime and fine concrete are the most effective (99% reduction of H_2S gas) cover materials for reducing H_2S gas emissions, while sandy and clayey materials showed average reduction efficiencies (77% to 98% effective) and coarse concrete was the least effective (23%). Cover materials that contain a mixture of soil, ash, and compost have also been shown to be effective in controlling H_2S gas emissions.

To achieve the most effective H_2S gas control, it is generally recommended that permanent covers be installed as soon as the final grade of C&D debris is reached. In areas that are inactive, but have not yet met final grade, temporary covers can be used. We encourage that cover materials be inspected frequently to check that no damage has occurred. It may also be effective to apply cover materials prior to large rain events, in order to prevent the gypsum waste from getting wet.

Capping/cover materials are effective when combined with other management practices, such as gas collection. Several states have reported success with this remedy for C&D debris landfills (Ref. 19).

At the WRI cleanup, USEPA used a clay cover combined with surface/stormwater control and leachate control & treatment to effectively control H_2S gas emissions (Ref. 18). As previously noted, maximum detectable concentration of hydrogen sulfide gas was reduced from 165 ppm to 0.043 ppm at the surface of the landfill.

4.6 Education and Training

Recyclers, transfer station operators, and landfill operators should understand how H_2S gas is produced in C&D debris landfills, particularly at those C&D debris landfills that meet the criteria identified in Section 3. Awareness of the mechanisms behind the formation of H_2S gas and methods that effectively prevent or restrict the formation of H_2S gas will support knowledgeable decision-making when working with C&D debris (Ref. 11).

Specifically, it is recommended that landfill operator training at a C&D debris landfill managing large amounts of pulverized gypsum include: 1) how to identify and/or segregate C&D debris containing pulverized gypsum drywall; 2) cover application and maintenance; 3) moisture control methods such as surface water and stormwater control procedures (e.g. ponding prevention) and proper leachate management, 4) H_2S gas identification; 5) onsite/perimeter inspections and H_2S gas monitoring methods (Note: This includes recognition of H_2S gas odors and to report the time, location, weather conditions, and any unusual site conditions); and 6) health and safety/emergency procedures involving H_2S gas (Ref. 18).

4.7 Active Gas Collection

Active gas collection and recovery systems, if properly designed, can collect and treat the effluent gas and effectively reduce H_2S gas emissions at C&D debris landfills. According to a USEPA Region 5 preliminary survey in May 2005, several states, which have had serious H_2S gas odor problems, reported success in controlling H_2S gas odors by requiring C&D debris landfills to install these systems in combination with covers (Ref. 19).

However, due to the high capital, operations, and maintenance costs, we believe that active gas collection systems be considered as one of the last control options to be implemented at a given site. (Note: If such a system is put into place, the owner and operator may want to consult a qualified professional engineer to design and construct the system.)

4.8 An Integrated Approach for the Identification and Remediation of H_2S Emissions

In some cases, owners and operators may find it appropriate to establish site-specific H_2S gas monitoring and response plans. Various state and/or local regulations may already require some type of monitoring at these facilities, however, H_2S gas specific monitoring systems discussed in this document can also be incorporated to provide additional assurance when needed.

Like all environmental monitoring plans, the main goal of an H_2S gas monitoring plan is to protect human health and the environment. Specifically, the goal of an H_2S gas monitoring and response plan is to prevent the inhalation of objectionable or unsafe concentrations of H_2S gas by onsite personnel and anyone who works or resides near a C&D debris landfill that disposed of C&D debris containing large amounts of pulverized gypsum drywall. A site owner's and/or operator's implementation of an early detection and response system for monitoring H_2S gas emissions may greatly reduce or eliminate potential need for future mitigation.

In order to create an effective monitoring plan, the owner operator may consider the following factors:

4.8.1 Site Location (Ref. 18)

It is recommended that the location of debris disposal facilities that contain large amounts of pulverized gypsum drywall avoid areas where the debris may become wet or saturated. These locations include wetlands, flood plains or areas prone to flooding, or areas that have a high ground water table. By keeping the gypsum dry, H_2S gas generation would likely not occur and the potential problems associated with it.

States and local governments limit the siting of new C&D debris landfills near residential areas. This would reduce potential concerns in the case of H_2S gas problems. The greater distance (that separates these facilities from near-by communities) provides more time for natural dispersion and dilution of H_2S gas emissions, which ultimately leads to a lower exposure rate. Specifically, the owner or operator should consider the site-specific potential for debris saturation and the distance to human receptors for any new or pre-existing site.

The aforementioned location factors were present at the WRI Site. USEPA noted that the site was located in an area where residents were within 100 feet of the facility. In addition, the WRI site is situated in a low, poorly drained, former wetlands area with soils rich in clay, which facilitated stormwater ponding and exposed the C&D debris to wet/saturated conditions.

4.8.2 Site Conditions

For C&D debris disposal facilities that handle large amounts of pulverized gypsum drywall, it is a good practice for a facility operator to acquire documentation for the following:

- ***Site topography***. Since H_2S gas is heavier than air, it tends to settle and concentrate in low-lying areas. Understanding the topography will help in identifying areas where H_2S gas may linger and would lead to more effective management of such emissions.
- ***On-site and off-site structures***. Structures where leachate may migrate and subsequently emit H_2S gas causing some exposures to workers and nearby residents are important to identify.
- ***Understanding of the water table and its seasonal fluctuation***. One of the main factors in H_2S gas generation from pulverized drywall is wetting of it. Understanding where the groundwater table is and keeping the pulverized debris containing gypsum drywall away from it helps in preventing H_2S gas generation. Knowing this also would help evaluate the maximum depth of any excavation to separation from groundwater.
- ***Location of other potential sources of H_2S gas in the area***. Debris disposal facilities that handle large amounts of pulverized gypsum drywall are not the only facilities that can be a potential source of H_2S gas. A poorly managed wastewater treatment plant may emit H_2S gas. Identifying the source of H_2S gas is very important in addressing any potential problems that may arise.
- ***Property boundaries and ownership adjacent to the facility***. The owner or operator may wish to gather information beyond the immediately adjacent properties based on site-specific knowledge in order to identify potential receptors. Different gas monitoring techniques or instruments may be appropriate on-site and off-site. Such information is helpful in the rare event where offsite H_2S gas emissions become a concern.

The owner or operator may also find it useful to assemble the following site-specific information:

- Records or information regarding the type of waste/debris disposed at the site.
- Facility construction details, including any liners or final cover.
- Details of any existing and/or operating gas extraction or venting system.
- Details of any existing gas monitoring system.
- Facility gas generation potential.
- Historical records regarding gas investigations and monitoring, visual or olfactory observations, inspections or complaints, odor problems.

4.8.3 Self Inspection Strategy

Because of the high sensitivity humans have to H_2S gas odor (Humans can smell 0.0005 to 0.3 parts per million of H_2S gas), the initial warning of potential problems may be by smell. This would most likely be in the form of complaints from neighbors or onsite workers about a rotten egg smell.

Therefore, we encourage that periodic site inspections be conducted, by the facility operator, mainly to identify signs of potential H_2S gas emissions and to ensure implementation of management practices, if any. The inspections can also serve to identify areas of high temperatures that may indicate a higher rate of degradation. The inspections might include a general screening for H_2S gas odors along the facility perimeter and are best conducted during the early morning or late evening hours since odors are most likely to occur at these times. Emissions may vary depending on temperature changes, as well as wind speed and direction.

(Note: As mentioned earlier, inspectors should be aware that at higher concentrations, at or above 100 ppm, individuals may not detect H_2S gas due to olfactory fatigue. For this reason, odor is not a reliable indicator of H_2S's presence at higher concentrations and may not provide adequate warning of hazardous concentrations)

If an H_2S gas meter is available, the owner or operator may wish to include sampling along the perimeter and over a grid pattern across the areas of waste or debris placement during daily inspections. Such sampling, conducted on a regular basis, could alert the owner or operator to the generation of H_2S gas. Gases could be released from the facility through fissures, cracks, uncovered areas, leachate ponds, or erosion gullies. Such areas may easily be repaired to reduce or eliminate off site migration. Early detection of potential off site migration may also allow the operator to improve operational practices and employ additional MPs, thereby reducing the need for more costly solutions in the future.

If H_2S gas odors are detected, the owner or operator can use a portable H_2S gas analyzer to quantify the extent and concentration of the H_2S gas emissions and compare them to applicable health standards. If the problem persists, we suggest that the owner and/or operator should consider a monitoring plan to quantify on-site and off-site H_2S gas levels. The plan would be site specific and could be modified as site-specific data becomes available. Initially, for example, monitoring can be conducted in downwind and low lying areas, especially if those areas are near potential receptors. Once sufficient data have been collected to determine the origin and extent of emissions, the monitoring plan can be updated to examine specific areas of concern.

The location of monitoring points is mainly a function of site-specific factors such as topography and atmospheric conditions. Understanding the site topography, as mentioned above, is helpful in identifying likely gas migration and accumulation locations and establishing monitoring points beyond the facility boundary. In addition, if on-site monitoring is considered appropriate, we believe that it be conducted in a manner that would facilitate delineation of areas with higher concentrations.

When H_2S gas monitoring is conducted, different gas monitoring instruments may be used for on-site workers and nearby residents, depending on the objective. For example, an instrument that is capable of detecting H_2S levels as low as 0.001 ppm (1.0 ppb) may be appropriate for perimeter monitoring to detect off-site migration. On the other hand, on-site monitoring to ensure personnel protection may only require an instrument that is capable of detecting H_2S gas levels at or above 1.0 ppm (1000 ppb). Instruments should be designed and calibrated specifically for H_2S. For maximum protection of the facility personnel, as well as the general public, proper sampling techniques and calibration should be followed. In addition, we encourage that trained personnel operate the monitors who understand the operating procedures and limitations of the instrument being used. For instance, monitors calibrated to detect H_2S gas may show interference from other sulfur gases.

If H_2S gas odor problems persist, meteorological data (i.e., temperature, wind speed and direction, precipitation and barometric pressure) may be collected and analyzed. For additional information on this topic, refer to EPA-454/R-99-005 and/or EPA-450/4-87-007.

Once the owner or operator has established the source, concentration and extent of the H_2S gas emissions, decisions concerning appropriate remedial action can be made. A few examples of the management practices outlined in this text include applying cover material, removing leachate, and diverting surface/stormwater from areas of debris placement.

4.9 Other Practices to be Considered

4.9.1 Community Outreach (Ref. 18)

Good community relations are part of every successful odor control program. Humans can detect the odor of H_2S gas at very low concentrations (as low as 0.0005 ppm). Even at low concentrations, H_2S gas can be offensive and complaints may occur, especially during unfavorable weather conditions. Therefore, we recommend that the owner or operator maintain effective communication with the surrounding community and encourage involvement.

At the WRI site, USEPA conducted regular meetings with the community and local government to ensure that they were aware of the removal activities and had a forum to express their concerns.

4.9.2 Local Fire Department Involvement

We recommend that the owner or operator establish action levels or be aware of required action levels that trigger notification to health officials, regulators, and local emergency response personnel.

5.0 H_2S Gas Off-Site Migration (WRI Site Case Study)

This section provides an example of monitoring and response (through a case study) in the event that H_2S gas migrates off-site into surrounding communities. These guidelines were used by USEPA, as part of its contingency plan, at the WRI site in Ohio, where a time critical removal action was initiated at a former C&D debris landfill to address H_2S gas releases to the surrounding community (visit www.epaosc.org/warrenrecycling). The contingency plan specifically focused on releases occurring as a result of on-site activities during USEPA's time-critical removal action. The following table summarizes actions required at the WRI site if certain H_2S gas conditions at the fenceline are achieved:

H_2S gas Concentration	Length of Time of Sustained Readings	Actions Required
.200 ppm	30 minutes at the fence line	1. Federal on-scene coordinator may advise residents to close windows and stay inside. 2. If resident gives permission, conduct air monitoring inside home. 3. If concentrations inside home are up to 200 ppb, FOSC should notify Warren City Fire Department and defer to their authority for community action.
1.0 ppm	10 minutes at the fence line	1. Take immediate action on-site to mitigate the cause of the gas release. 2. Alert the Warren City Fire Department and defer to their authority for community action.
3.0 ppm	5 minutes at the fence line	1. Take immediate action on-site to mitigate the cause of the gas release. 2.Alert the Warren City Fire Department and defer to their authority for community action.
25 ppm	sustained for any length of time, at the fence line	1. Take immediate action on-site to mitigate the cause of the gas release. 2. Inform residents to close windows, shut off air conditioners, and stay inside. 3. Alert the Warren City Fire Department and defer to their authority for community action.

This table pertains to releases that occur as a result of on-site work actions.

REFERENCES:

1. Agency for Toxic Substances and Disease Registry. Toxicological profile for hydrogen sulfide. Atlanta: US Department of Health and Human Services; 1999

1a. Agency for Toxics Substances & Disease Registry. Sept. 2004. Draft Toxicological Profile for Hydrogen Sulfide, http://www.atsdr.cdc.gov/toxprofiles/tp114.html .

2. Agency for Toxics Substances & Disease Registry, Medical Management Guidelines for Hydrogen Sulfide. http://www.atsdr.cdc.gov/MHMI/mmg114.html, accessed April 27, 2006.

3. EPA Region 9 Preliminary Remediation Goals. http://www.epa.gov/region9/waste/sfund/prg/ . Accessed February 16, 2006.

4. EPA Region 3 Risk Based Concentration Table. http://www.epa.gov/reg3hwmd/risk/human/index.htm . Accessed February 16, 2006.

5. EPA Acute Exposure Guidelines, http://www.epa.gov/oppt/aegl/chemlist.htm. Accessed April 27, 2006.

6. California Environmental Protection Agency, http://www.oehha.ca.gov/air/pdf/acuterel.pdf. Accessed April 27, 2006.

7. Occupational Safety and Health Administration, http://www.osha.gov/dts/chemicalsampling/data/CH_246800.html Accessed April 27, 2006.

8. USEPA , Characterization of Building Related Construction and Demolition Debris in the United States, Construction and Demolition Debris, June 1998.

9. USEPA , Construction and Demolition Debris; http://www.epa.gov/epaoswer/non-hw/debris-new/basic.htm ; Accessed April 27, 2006.

10. Timothy G. Townsend et al. Dec. 2000(Updated Jan. 2002), Gypsum Drywall Impact on Odor Production at Landfills: Science and Control Strategies, Florida Center for Solid and Hazardous Waste Management, State University System of Florida.

11. New Hampshire Department of Environmental Services, November 22, 2004 Interim Best Management Practices for the Use of C&D Process Fines.

12. Bogner and Heguy, March/April 2004, Hydrogen Sulfide from Landfilled Construction and Demolition Debris: When and How , MSW Management.

13. Hardy Associates (1978) Ltd., December 19, 1984, Gypsum Subcommittee of the Lower Mainland Refuse Project. Investigation of Means to Control Sulphide Production in Drywall Landfill Disposal Operations.

14. Gypsum Association, January 1991, Treatment and Disposal of Gypsum Board Waste Industry Technical Paper.

15. Timothy G. Townsend, et al, January 31, 2001, Recycling of Discarded Gypsum Drywall in Florida, Final report to the Florida Department of Environmental Protection, by University of Florida Department of Environmental Engineering Sciences.

16. Plaza, Townsend, Cover Materials for the Mitigation of Hydrogen Sulfide from C&D Landfill Gas, Department of Environmental Engineering Sciences, University of Florida. SWANA E-Training, July 13, 2005.

17. Shaw Environmental, EMCON/OWT, Inc. June 24, 2004, Final Report on Best Management Practices, Construction & Demolition Fines as Landfill Cover Material.

18. USEPA , Pollution Reports 1-16, Warren Recycling, Warren Ohio EPA Region V, http://www.epaosc.org/polrep_profile.asp?site_id=1622 , Accessed April 28, 2006.

19. USEPA Region 5, Letter to Ohio EPA, June 13, 2005, Hydrogen Sulfide Problems at Construction and Demolition Landfills at States Outside of Ohio in the United States.

20. Reinhart, et al, November 2004, Control of Odors from Construction and Demolition (C&D) Debris Landfills, Florida Center for Solid & Hazardous Waste Management, University of Florida.